Army Materiel Systems Analysis Activity

# TECHNICAL REPORT NO. TR-2016-28

# DEVELOPMENT RISK METHODOLOGY FOR WHOLE SYSTEMS TRADE ANALYSIS

**August 2016**

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PEO GCS requested AMSAA to conduct a verification and validation (V&V) of the Whole System Trade Analysis Tool (WSTAT). In the early stages of the V&V for development risk, it was discovered that the original risk rating and methodology did not actually represent development risk, because consequences were not considered (only likelihood). As a result, an appropriate development risk methodology needed to be created for the intended WSTAT applications. In addition to incorporating consequence into the risk methodology, AMSAA created a methodology for the technology distributions, considered criticality of technologies, developed a closed form algorithm, and created a risk rating approach. The purpose of this report is to document how development risk was created for WSTAT.

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## LIST OF ACRONYMS

| | |
|---|---|
| AMSAA | - U.S. Army Materiel Systems Analysis Activity |
| AoA | - Analysis of Alternatives |
| C | - Consequence |
| DoD | - Department of Defense |
| DT | - Developmental Technology |
| GCS | - Ground Combat Systems |
| JCIDS | - Joint Capabilities Integration and Development System |
| L | - Likelihood |
| MS | - Milestone |
| O&S | - Operations and Sustainment |
| P.95 | - 95$^{th}$ percentile of a risk distribution |
| PEO | - Program Executive Office |
| SME | - Subject Matter Expert |
| SNL | - Sandia National Laboratory |
| SO | - Schedule Overrun |
| TRL | - Technology Readiness Level |
| VB.NET | - Visual Basic.NET |
| V&V | - Verification and Validation |
| WSARA | - Weapon Systems Acquisition Reform Act |
| WSTA | - Whole System Trade Analysis |
| WSTAT | - WSTA Tool |

**DEVELOPMENT RISK METHODOLOGY FOR WHOLE SYSTEMS TRADE ANALYSIS**

## 1. INTRODUCTION

Whole Systems Trade Analysis (WSTA) is a powerful decision tool used to model the relationship between design decisions and stakeholder value in order to inform and potentially influence requirements documents and associated specifications. The WSTA tool (WSTAT) can also be used to conduct cost informed trades analysis based on holistic design choices, while understanding the opportunity cost of each choice. Program Executive Office (PEO) Ground Combat Systems (GCS) developed the WSTA methodology, and has successfully applied it across several programs. WSTAT integrates otherwise separate subsystem models into a holistic system view, mapping critical design choices to consequences relevant to stakeholders, in order to avoid oversimplification, avoid sub-optimization, and find the balance across competing objectives. Potential applications for the tool include capability gap assessments (originated by the Joint Capabilities Integration and Development System (JCIDS))[1], technology exploitation, requirements definition, early cost informed trades, requirements analysis, Analysis of Alternatives (AoA), contractor trades, and technology trade options. WSTA and its potential applications supports and complies with the Weapon Systems Acquisition Reform Act (WSARA) of 2009 [2].

WSTA has opened trade space exploration by allowing the tool to evaluate trillions of potential system configurations to then return a handful of configurations which best meet design and programmatic criteria [3]. WSTA holistically displays system results along with the five value dimensions and their consequences. These dimensions are: performance, unit cost, operations & sustainment (O&S) cost, development risk, and growth potential. Identifying the tradeoff between these competing objectives is a non-trivial task and requires the values and preferences of key stakeholders, including users and Army leadership. Figure 1 depicts a notional plot of the configurations which best meet design and programmatic criteria (these "best" configurations are called Pareto Optimal Solutions).

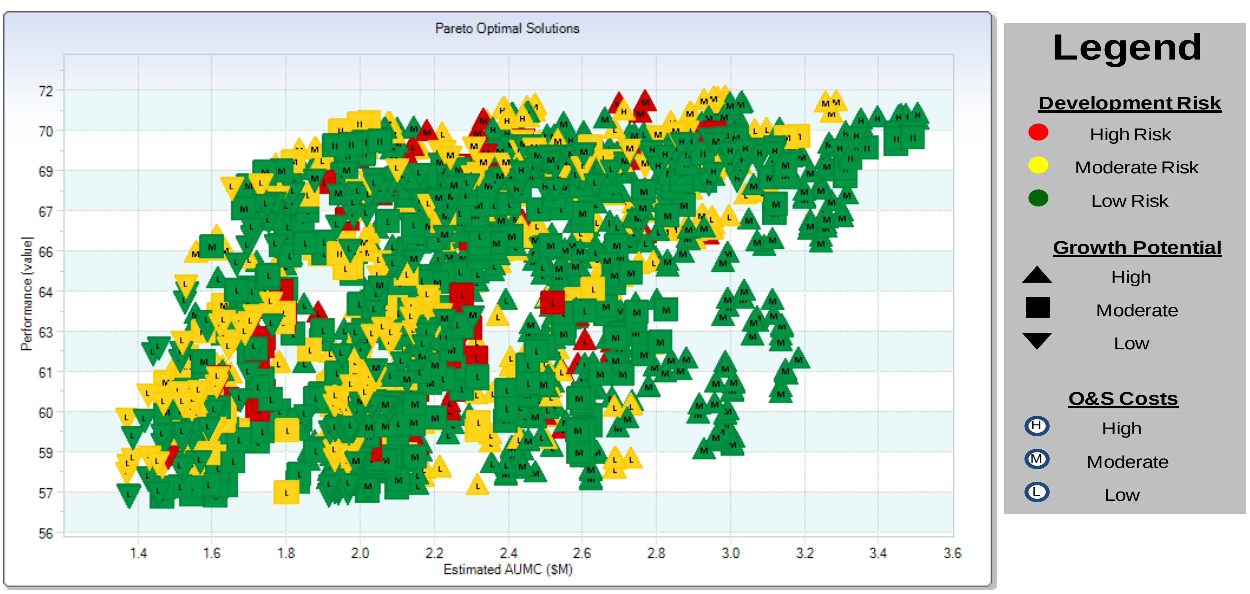


**Figure 1. Pareto Optimal Solutions.**

PEO GCS requested U.S. Army Materiel Systems Analysis Activity (AMSAA) to conduct a verification and validation (V&V) of WSTAT. In the early stages of the V&V, it was discovered that the original risk rating and methodology did not actually represent development risk, because consequences were not considered (only likelihood). As a result, an appropriate development risk methodology needed to be created for the intended WSTAT applications. In addition to incorporating consequence into the risk methodology, AMSAA created a methodology for the technology distributions, considered criticality of technologies, developed a closed form algorithm, and created a risk rating approach. For the WSAT application, development risk is defined as the risk of not delivering one or more technologies on time at the Milestone B schedule date.

The new development risk methodology contains a risk score, a value score, and a risk rating. The methodology was presented to and accepted by PEO GCS and Sandia National Laboratories (SNL). The risk and value scores are currently being utilized in the WSTA genetic algorithm to explore the trillions of configurations. Pending the availability of funding, the risk rating algorithm will be incorporated into WSTA and applied to a final holistic mapping of the "best" configurations. The purpose of this report is to focus on how development risk was created for WSTAT and is intended for an analyst involved in the development or application of WSTAT.

## 2. DEFINITION AND OVERVIEW OF DEVELOPMENT RISK

Risk is defined [4] by some undesired event, the likelihood of that event, and the consequence if the event occurs. Based on the definition of risk and intended use of WSTAT, development risk contains these three basic elements:

1. An event, which is time or schedule related: Not delivering one or more technologies on time at the Milestone (MS) B schedule date.
2. A likelihood (L) for the event.
3. A consequence (C) if the event occurs (add time to the schedule – a schedule overrun).

In order for development risk to be incorporated into the existing WSTAT framework, AMSAA had to develop an approach for determining a risk score that considered the three elements listed above. Prior to developing a method for determining a risk score, AMSAA improved the existing technology time distributions utilized in WSTAT. In addition, AMSAA developed a method for measuring technology criticality using consequence. The technology time distributions and technology criticality were then incorporated in a Monte Carlo simulation to determine a risk score. Since the Monte Carlo simulation would significantly increase the runtime for WSTAT, a closed form algorithm was developed to instead implement in WSTAT. Lastly, a method for creating a risk rating (high, moderate, low) was developed. The following sections of this report describe the improvements for the technology time distributions, incorporation of criticality as a component of consequence, creation of a risk score, development of a closed form algorithm, and creation of a risk rating.

## 3. CREATION OF AN IMPROVED TIME ASSESSMENT

### 3.1 Existing Time Assessment Approach.

WSTAT produces trillions of potential system configurations, each of which are composed of many underlying technologies. Development times for these technologies (specifically, the time to reach MS B) within each system configuration are what drives the development risk score and rating. The initial steps of applying the WSTA development risk process are to identify all possible technologies of interest for the system under consideration, and to identify subject matter experts (SMEs) that are knowledgeable regarding the current status, potential risks, and estimated development times associated with each technology. The established WSTAT framework utilizes elicitation techniques with these SMEs to evaluate the $10^{th}$, $50^{th}$, and $90^{th}$ percentile development times to reach TRL 6 for each technology. Figure 2 illustrates a typical time assessment for one notional technology. This time assessment is a probability distribution [7] where the area under the curve totals 1.0.

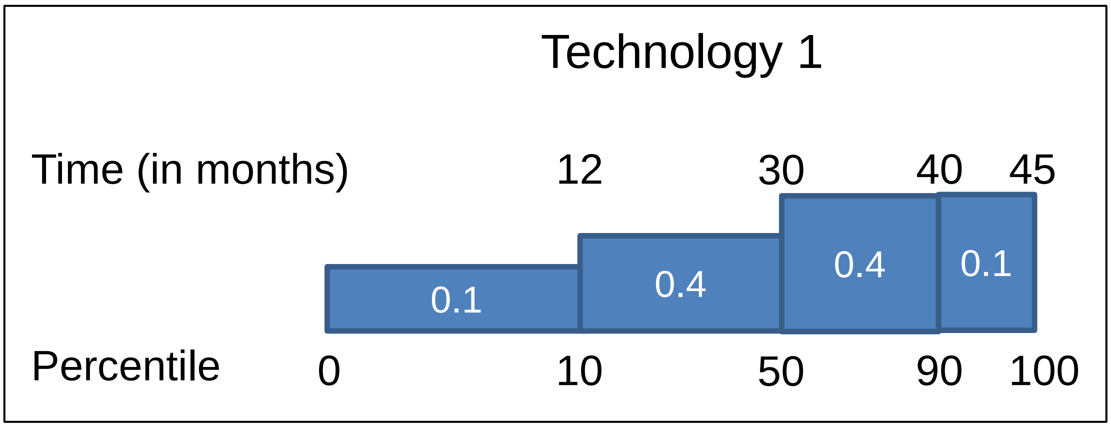


**Figure 2. Initial Completion Time Assessment.**

The percentile time values (in months) of 12, 30, and 40 months (or calendar dates could be used) are assessed from the SMEs at a workshop. Using these percentile time values, the existing WSTAT framework determines that the $100^{th}$ percentile is 45 months. As shown in the probability distribution in Figure 2, the area under the curve totals 1.0.

### 3.2 Improved Time Assessment Approach.

Notice that the probability distribution in Figure 2 has no "right tail". It is documented that time distributions [5] usually have a right tail, since uniformity in the tail of a time assessed distribution is not realistic. Figure 3 depicts the improved notional distribution previously shown in Figure 2.

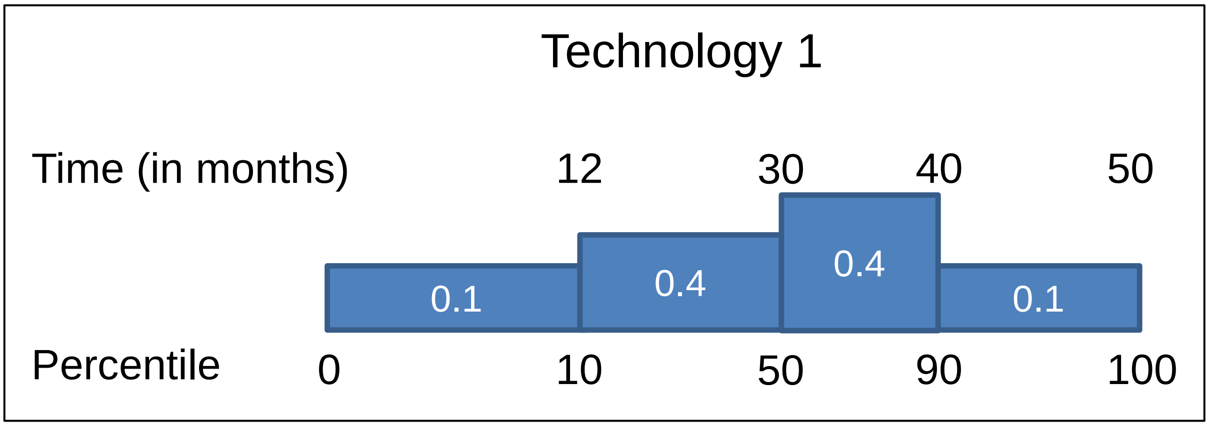


**Figure 3. Improved Completion Time Assessment.**

The height of the last rectangle for the original probability distribution (Figure 2) is cut in half horizontally and the length of the rectangle (Figure 3) becomes twice as long. The new $100^{th}$ percentile now becomes 50 months. This creates a tail in Figure 3 which better represents the completion time distribution. The area of this last rectangle remains 0.1 by design.

## 4. MEASURING CRITICALITY USING CONSEQUENCE

Criticality of a developmental technology can be incorporated into the risk of that technology. The concept of criticality is illustrated in this section by adjusting the consequence or schedule overrun based on the criticality level.

Suppose two technologies both overrun the schedule by the same number of months (e.g., eight months) and one technology is critical and the other is not. While both technologies will probably take eight months to complete, the critical technology carries much more schedule risk than the lower critical technology because the more critical technologies could impact key program activities, such as:

- Cause a MS B or C date to change if an overrun occurred,
- Cause more integration, manufacturing, and development issues in the future, or
- Cause operational testing & evaluation issues due to being a novel technology.

The three impacts listed above should be considered when determining whether or not a technology is critical. A non-critical technology is not involved in any of these three events, whereas a critical technology plays a role in at least one of these events. In the previous example with two technologies, the critical technology will have a higher consequence than the non-critical technology. Consequence in this case is measured by schedule overrun, or how much the schedule slipped beyond the MS B date due to that technology. Normally, critical and non-critical technologies would not have the same consequence. Hence, the non-critical technology should have a consequence < 8. The process or mechanism to determine this involves reducing the consequence (slippage or overrun of “8”) for the less critical technologies. The reduction amount is called “slack”. The following are two possible criticality flags:

- High (i.e., the technology needs all of the overrun time – no slack) or
- Low (i.e., the technology does not need all of the overrun time – slack is required)

Slack would be applied to the low criticality flags for a given technology. This means that if a technology has a low criticality flag, then some amount of "slack" is subtracted from the schedule overrun (or consequence) for that technology. Slack is based on number of months and is determined by the user based on its product structure and technology type (i.e. a user created table). For example, suppose a certain system configuration has one developmental technology (DT) with a completion time distribution. DT #1 is assigned a low criticality with a 6 month slack constant (based on its product structure and type). Suppose DT #1 took 18 months to complete and MS B was in 10 months. Figure 4 depicts this notional example.

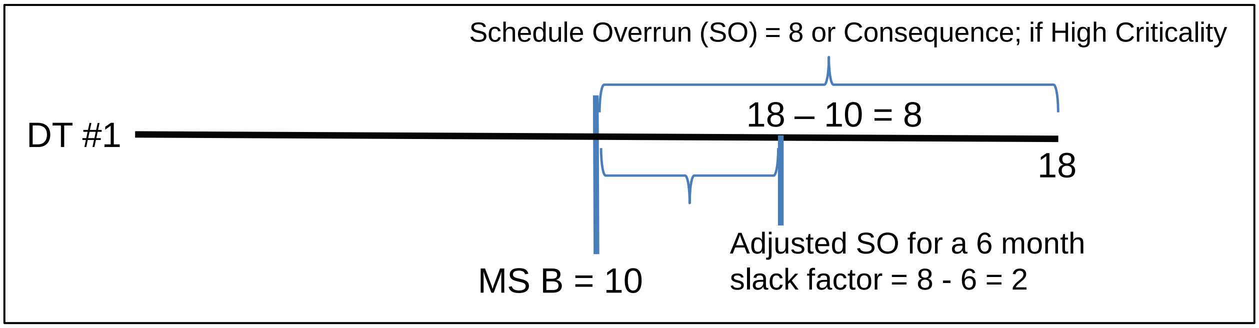


**Figure 4. Criticality and Schedule Overrun.**

Since DT #1 was assigned a low criticality, then the schedule overrun (SO) was reduced from 8 months to 2 months. If DT #1 had been assigned a high criticality, then the SO would have been the full 8 months.

## 5. TRANSFORMATION OF TIME ASSESSED DISTRIBUTIONS

This section addresses how the criticality assignment affects the time assessed distribution for a given DT. To illustrate this concept, a notional example will be used. Suppose a DT (e.g., radio) was originally assessed to reach TRL 6 with the uniform distribution depicted below in Figure 5 and MS B = 30 months.

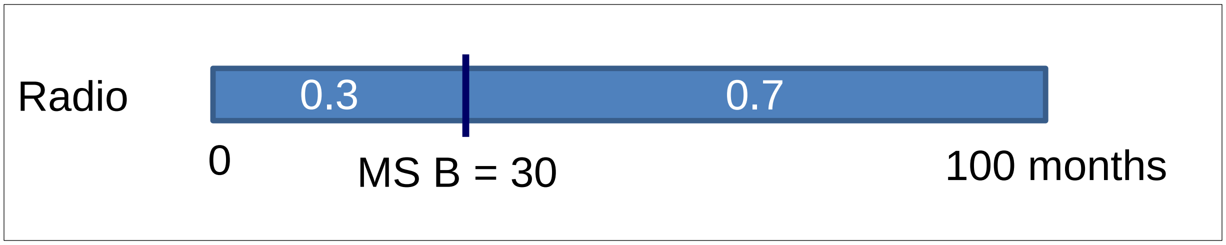


**Figure 5. Radio TRL 6 Time Assessment.**

Since the maximum time is 100 months, the height of the rectangle in Figure 5 must be 1/100 = 0.01 because the area of this rectangle must be 1.0. If the radio was assigned a low criticality,

with slack constant of K = 5 months determined by the user based on the radio family of technologies (this is a different notional example than in section 4). Then the original time assessed distribution in Figure 5 transforms into the following distribution, depicted below in Figure 6 (based on the criticality rules from Section 4).

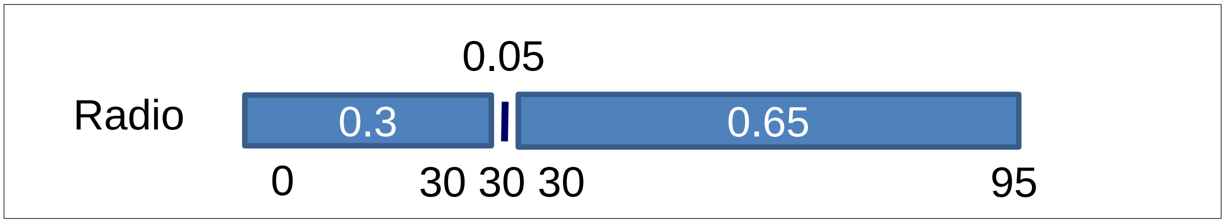


**Figure 6. Transformed Radio TRL 6 Time Assessment.**

Note that the area of the two rectangles are 0.3 and 0.65 (the height of each rectangle remains at 0.01) and the probability of completing in exactly 30 months is 0.05 because of the 5 month slack shift. Note: Times > 30 become: 30 + schedule overrun after slack of 5 months is applied. Therefore, 5% of the original times in Figure 5 (times between 30 – 35) will be 30, since the schedule overruns will be zero after slack is applied (negative schedule overruns must be 0 or bigger – time is a positive continuous distribution).

## 6. CREATION OF A RISK SCORE

The development risk methodology consists of a risk score, a value score, and a risk rating. This section illustrates how the risk score is developed by extending the example from Figure 4 in Section 4. Suppose a certain system configuration has two DT's, each with different completion time distributions. DT #1 is assigned a low criticality (with a 6 month slack constant) and DT #2 is high criticality (no slack). Suppose DT #1 took 18 months to complete and DT #2 took 11 months to complete, where MS B was in 10 months. Let this be one instance or run of a Monte Carlo simulation [6]. The maximum schedule overrun for these two DT's is MAX(2, 1) = 2, illustrated in Figure 7 example.

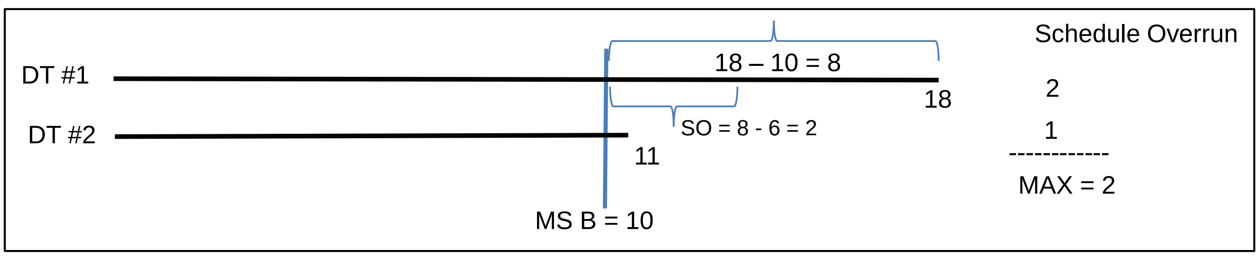


**Figure 7. Notional System Configuration with Two DT's.**

The next step is to perform this Monte Carlo simulation a large number of times (e.g., 1000 times) to create a distribution of schedule overruns, where no overrun is assigned a 0. This resulting distribution is called the risk distribution. Suppose the 95$^{th}$ percentile of this distribution

is P.95 = 3.75 months. A notional risk distribution and P.95 look like the following graph depicted in Figure 8.

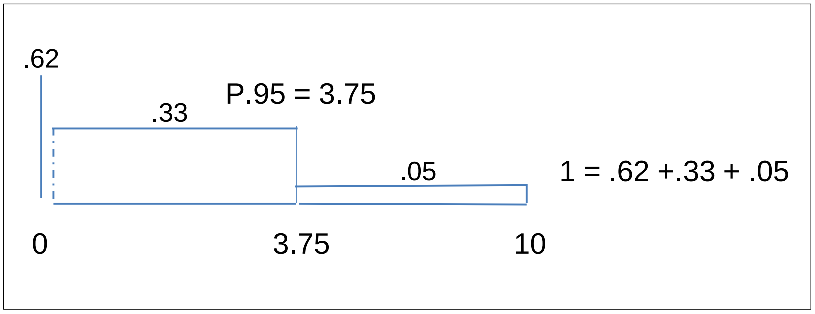


**Figure 8. Notional Risk Distribution.**

The sum of the probabilities for all schedule overruns (0 overrun implies system completed before MS B) sums to 1.0, therefore the risk distribution is a probability distribution [5]. This risk distribution incorporates all three elements of risk that were discussed in Section 2 (an event, the likelihood of the event, and the consequence of the event). The P.95 value represents the risk level for a particular system configuration. Higher values of P.95 are riskier than lower values. The idea to focus on is the relative risk of all system configurations in relationship to each other. The $95^{th}$ percentile was chosen to assure this relative risk spread – any large percentile (i.e., $85^{th}$, $90^{th}$, etc.) may have also worked because the relative rankings of risk will not change. P.95 now becomes the WSTA development risk score and represents the risk of a particular system configuration.

## 7. CLOSED FORM SOLUTION TO DEVELOPMENT RISK

Since a WSTA development risk score is needed for each of the trillions of system configurations, it is not practical for the tool to run that many Monte Carlo simulations. This section documents a closed form solution that was developed to address this problem. To illustrate this algorithm the risk distribution from Figure 8 will be used. This risk distribution represents a single system configuration. Suppose the probability of no schedule overrun (0) for this configuration is 0.62, and MS B = 10 months. This 0.62 probability is simply the product of the probabilities that each DT achieves TRL 6 in less than 10 months. This configuration has two DT's, where the probability of no schedule overrun (0) for DT #1 and DT # 2 is 0.8 and 0.775 respectively, for MS B = 10 months, thus 0.8 * 0.775 = 0.62.

The goal is to find the $95^{th}$ percentile (P.95) of this particular risk distribution. If the probability of no schedule overrun (0) for this configuration was 0.95, and MS B = 10 months, then P.95 = 0. To find this P.95 without using simulation, it is necessary to utilize a binary search algorithm to find the number of months (X) when the probability of no schedule overrun (0) for this configuration is 0.95. After conducting the binary search, suppose X = 13.75 months. Therefore the P.95 of the risk distribution in Figure 8 is 13.75 – 10 = 3.75 months.

## 8. RISK VALUE SCORE

The existing WSTAT framework utilizes value scores and preferences, which need to be evaluated for the trillions of possible risk scores. To do this the user decides what the value curve will be based on their preferences. For example, a low preference to P.95 scores between 5 and 10 months, medium preference for scores between 3 and 5 months, and high preference or value for scores between 0 and 3 months. A plot of this value curve might look like the following graph shown in Figure 9. The risk and value scores are ordered worst to best on their respective axes.

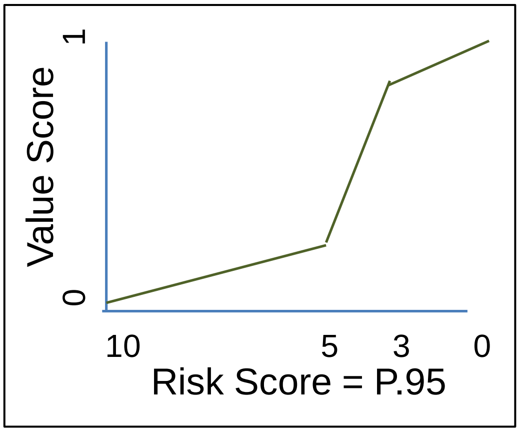


**Figure 9. Value Curve.**

Note that if a different percentile was used, one may still conclude the same value curve. The value score is then used in the WSTA genetic algorithm to explore the trillions of configurations to select the "best" configurations.

## 9. CREATION OF A RISK RATING

Once the best system configurations are selected from the WSTA genetic algorithm, a risk rating needs to be assigned to each of the remaining configurations. This section discusses the methodology behind the steps to create a risk rating for an alternative.

Suppose P.95 = 6.8 months and L = 0.9 (1 – L = 0.1). L is the likelihood of not delivering one or more technologies on time at the MS B schedule date. Figure 10 is an approximation for the original risk distribution. The P.100 (100$^{th}$ percentile) of 8.1 months was determined by the maximum of the 100$^{th}$ percentile for all DT time distributions.

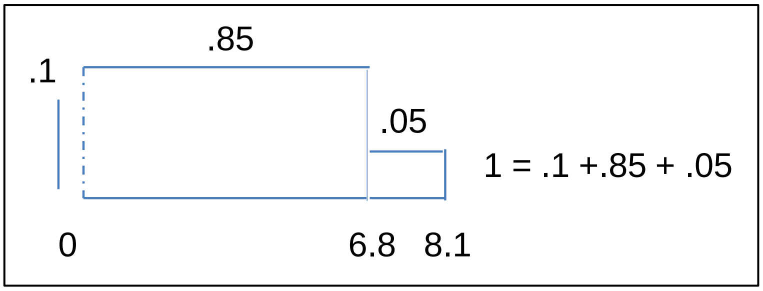


**Figure 10. Original Risk Distribution.**

The original risk distribution in Figure 10 utilizes both L (1 - .1 = .9) and consequence (C) within the same distribution. Consequence is measured as schedule overruns. Let's separate L and C into two parts by only considering the distribution of schedule overruns. Figure 11 shows how the original risk distribution from Figure 10 is converted into a consequence distribution. The median of the consequence distribution is 3.6 months. Assign C = 3.6 and L = 0.9.

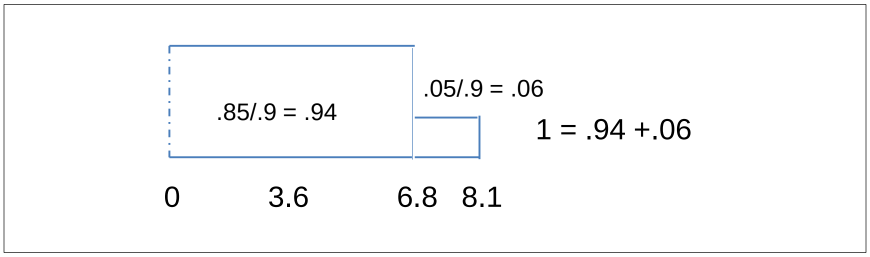


**Figure 11. Consequence Distribution.**

The final step is to assign a risk rating (high = red; moderate = yellow; or low = green) based on the L and C values. The preferences of the WSTA user ideally need to be reflected in the risk matrix and L and C value bins. Figure 12 shows the DoD Risk Reporting Matrix as a starting point.

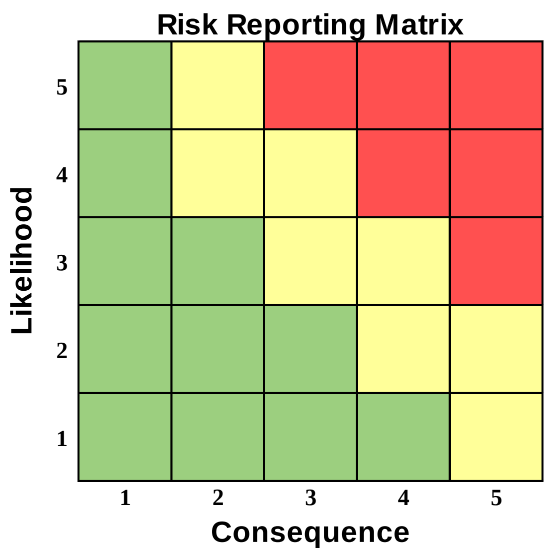


**Figure 12. DoD Risk Reporting Matrix.**

The preferences of the user are reflected by the location of the three colors in Figure 12 and the definitions of the L and C bins. Figure 12 is an example of the DoD Risk matrix and is not necessarily the preferences of the WSTA users. Next, it is necessary to define bins for each of the five L and C levels. An example of a risk matrix with the L and C bins defined is shown in Figure 13.

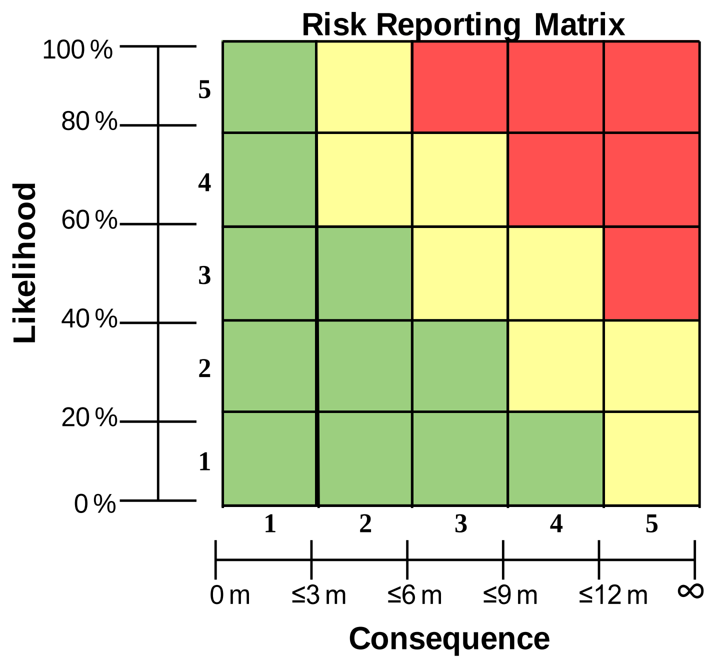


**Figure 13. Risk Matrix with Bin Definitions.**

L and C definitions to aid in defining the bins may look like the following two tables (Tables 1 and 2). The Likelihood and Consequence level definitions may be tailored for specific WSTA applications.

**Table 1. An Example of Likelihood Definitions.**

| Level | Likelihood | Probability Ranges |
|---|---|---|
| 1 | Not Likely | L <= 20% |
| 2 | Low Likelihood | 20% < L <= 40% |
| 3 | Likely | 40% < L <= 60% |
| 4 | Highly Likely | 60% < L <= 80% |
| 5 | Near Certainty | L > 80% |

Notice in this example (Table 1) that the likelihood values are evenly divided – this may not always be the preference.

**Table 2. An Example of Consequence Definitions.**

| Level | Schedule |
|---|---|
| 1 | Negligible schedule slip. |
| 2 | Schedule slip, but able to meet key dates and has no significant impact to slack on critical path. |
| 3 | Schedule slip that impacts ability to meet key dates and/or significantly decreases slack on critical path. |
| 4 | Will require change to program or project critical path. |
| 5 | Cannot meet key program or project milestones. |

If the alternative with L = 0.9 and C = 3.6 months is applied to the risk matrix in Figure 13, the risk rating would be moderate (yellow).

## 10. COMPARISON OF RISK METHODOLOGIES USED FOR WSTA AND AoA's

During the creation of the WSTA development risk methodology, many risk options were explored. The creation of the WSTA risk methodology led to significant improvements and additions to AMSAA's independent schedule risk assessments that support AoA's. Some of these enhancements were related to schedule risk ratings, integrated modeling, tradespace analysis, and joint probability statements.

The risk methodologies for WSTAT and AMSAA's risk assessments for AoA's have different intended uses, although there are many similarities. The WSTAT risk methodology is appropriate for pre-selecting the best system configurations/alternative designs, but is not intended to replace AMSAA's AoA Risk Methodology. Figure 14 shows a comparison of risk methodologies:

**WSTAT Development Risk Methodology**

- Intended Use: **Pre-AoA** to assess trillions of potential system configurations.

1. Completion time assessed using **TRL** (MS B target date) for **all technologies** by eliciting **10th, 50th and 90th percentiles** from SMEs.
2. **Criticality** of technologies is established based on impact to schedule (High or Low).
3. **Low criticality is addressed with slack constant** (original system configuration level **performance is still 100%** as planned).
4. System configuration level risk assessment (consequence is schedule overrun) is done at MS B to create **Risk / Value Score & Risk Rating**.

**AoA Schedule Risk Methodology**

- Intended Use: **AoA** to assess a limited number of potential alternatives (~4-6).

1. Completion time assessed using **TRL, IRL, & MRL** (MS B & C target dates) by eliciting **triangular distributions (min, max, most likely)** for **key technologies** from SMEs during a **Risk Workshop**.
2. **Critical** technologies are established based on assessment of whether a technology is 'key' which means potentially having an impact to the schedule.
3. **Non-critical** technologies are not considered.
4. Alternative level risk assessment (consequence is schedule overrun) is done at MS B & C to assign **Risk Rating**.

**Figure 14. WSTAT Development & AoA Schedule Risk Methodologies.**

## 11. CONCLUSION

AMSAA was tasked with conducting a V&V of WSTAT. In the early stages of the V&V for development risk, it was discovered that the original risk rating and methodology did not actually represent development risk, because consequences were not considered (only likelihood). As a result, an appropriate development risk methodology needed to be created for the intended WSTAT applications. In addition to incorporating consequence into the risk methodology, AMSAA created a right tail methodology for the technology distributions, considered criticality of technologies, developed a closed form algorithm, and created a risk rating approach.

The development risk methodology was designed to address the requirement to assess risk within the WSTA framework. This requirement was a risk score, value score, and a risk rating level for each of the many system configuration options. The risk and value scores are currently being utilized; however, the risk rating algorithm requires additional work to implement and is not currently utilized. Implementation of the risk rating algorithm will be conducted as part of future specific customer applications of WSTAT. The information learned from creating the development risk methodology also led to many enhancements to AMSAA's independent schedule risk assessments that support AoA's.

## REFERENCES

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